Air Sparging for Site Remediation

Battelle

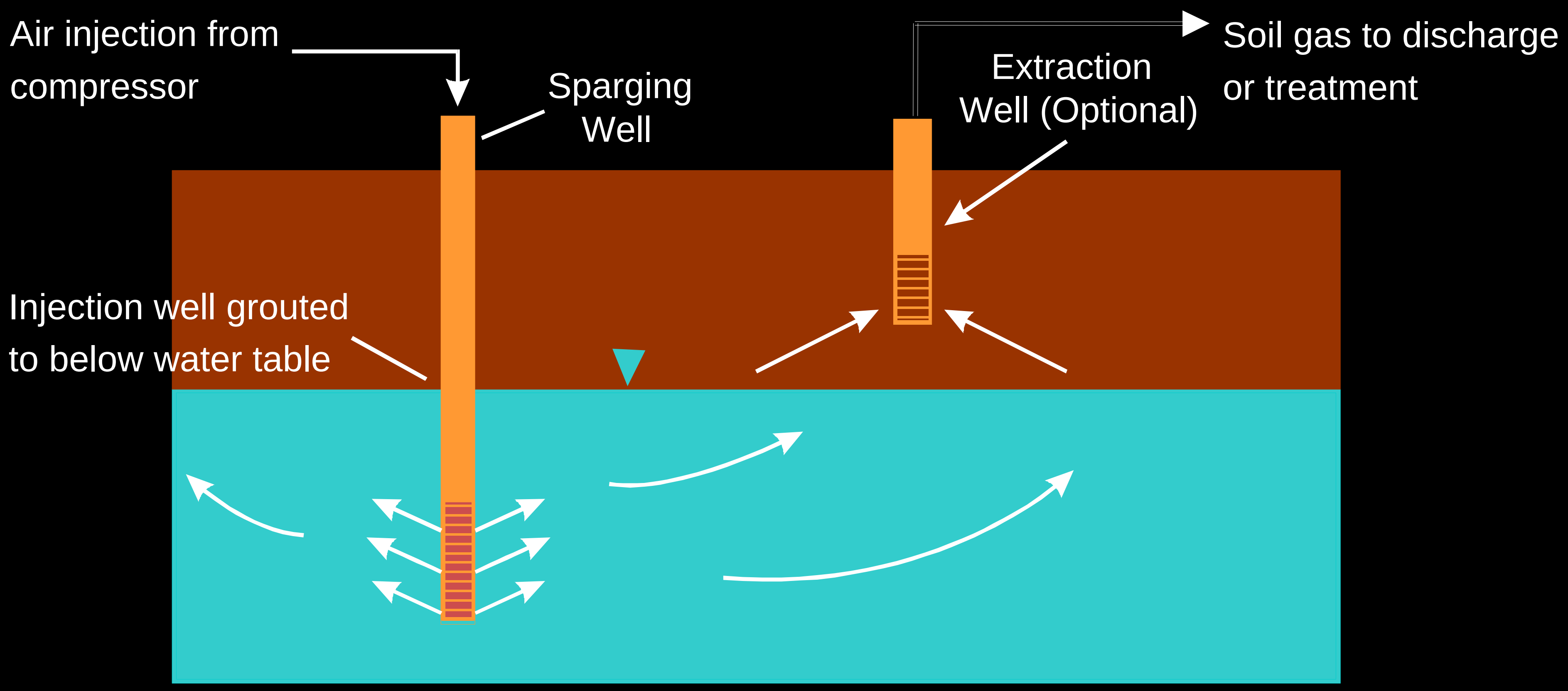
Topics Covered

- **What is air sparging?**
- How does air sparging work?
- Implementing air sparging
  - Site characterization
  - Pilot studies
  - Field design
  - Process monitoring & site closure
- Cleanup times and costs
- Examples: Port Hueneme, CA and DODHF Novato, CA
- Summary

Definition of Air Sparging

- Air sparging: the introduction of air beneath the water table to promote site remediation
- Air sparging relies on two basic mechanisms: volatilization and biodegradation
- Air sparging may refer to in-well aeration or air injection directly into the aquifer
- As discussed in this seminar, air sparging refers to air injection directly into the aquifer

Schematic Diagram of a Typical Air Sparging System



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Applicability of Air Sparging

- Treatment of dissolved contaminants in groundwater
- Treatment of contaminants in unsaturated zone from air movement out of groundwater
- Contaminants must be either aerobically biodegradable or volatile to allow stripping
  - Petroleum hydrocarbons (source zone) and chlorinated solvents (dissolved-phase zone) are good candidates
  - MTBE is possible - further research is needed

Air Sparging Assessments

- Air sparging is widely applied, but has not been well studied until recent years
- Three documents provided best summary of air sparging data up until 1994
  - USEPA Assessment (1993)
  - Johnson et al. (1993) – “An Overview of In Situ Air Sparging”
  - API Survey (1994)

Air Sparging Assessments

- U.S. EPA (1993)
  - Summary of recommended contaminant properties and soil structure
- Johnson et al. (1993)
  - Summary of air sparging design to date and recommendations for research needs
- API (1994)
  - Evaluation of unpublished performance data, primarily from petroleum company sites
  - Majority of sites did not have adequate data collected to include in study

In Situ Air Sparging – Questions

- What happens when air is injected into an aquifer?
- What is the role of volatilization versus biodegradation (oxygenation)?
- What factors affect performance?
- How should the process be monitored?
- Can data from short-term tests be extrapolated to long-term performance?
- Is vapor recovery necessary?
- How should systems be designed?

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US Navy/US Air Force Air Sparging Study

- In 1996, the US Navy and US Air Force collaborated on an intensive study of air sparging
- Study focused on determining optimal monitoring techniques and resolving design issues
- Expert panel was convened consisting of researchers from government, academia and industry to provide input to methods and data interpretation
- Data presented in this seminar is based on information gained from this study

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Principles of Air Sparging

- Air flow from injection well to vadose zone is central feature of air sparging
- Conceptual model used to described air flow
  - ① When air is injected into well, standing water in well bore is displaced downward and through well screen until air/water interface reaches top of well screen

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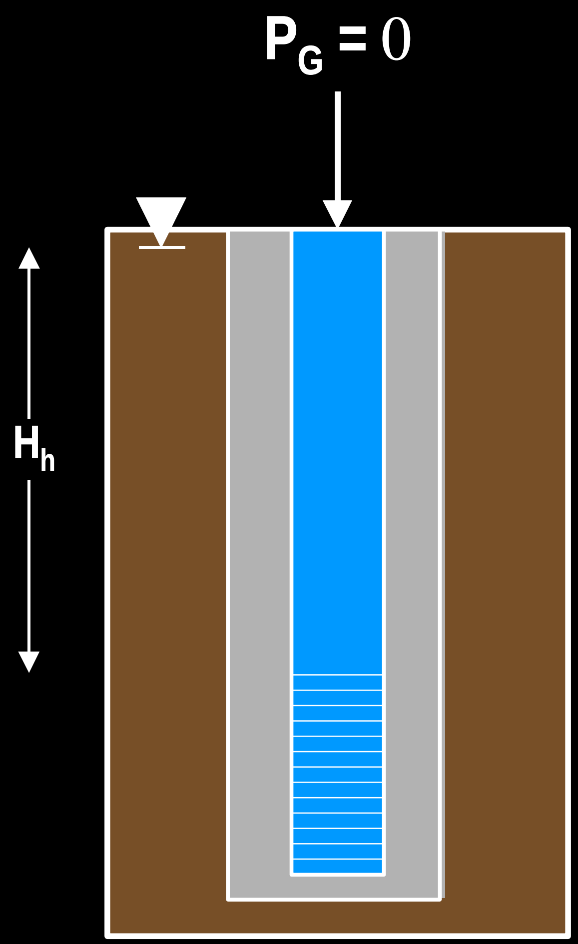
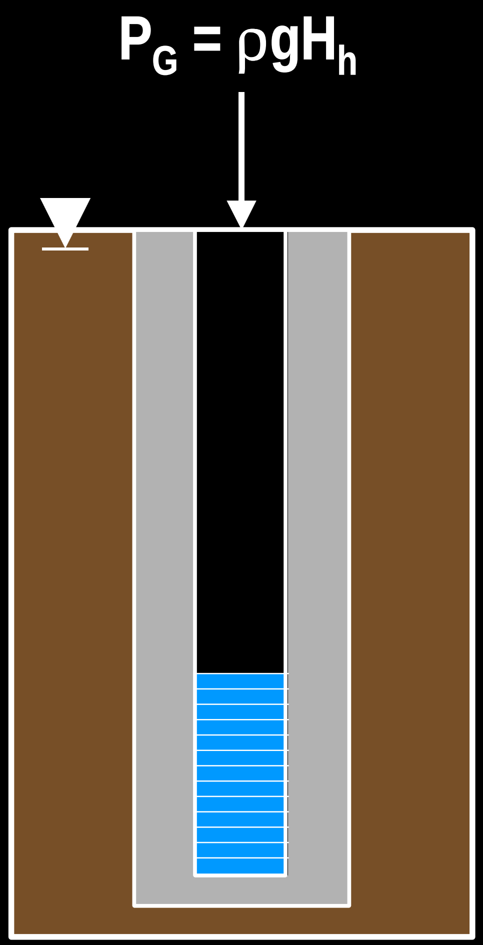
Conceptual Model



P_G	=	gauge pressure
ρ	=	$1.0\ g/cm^3$
g	=	$980\ cm/s^2$
H_h	=	hydrostatic head

Air Injection



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Principles of Air Sparging

- Conceptual model used to described air flow
  - ① When air is injected into well, standing water in well bore is displaced downward and through well screen until air/water interface reaches top of well screen
  - ② For injected air to penetrate aquifer, air pressure in excess of hydrostatic pressure is necessary
    - – excess pressure = air entry pressure of packing

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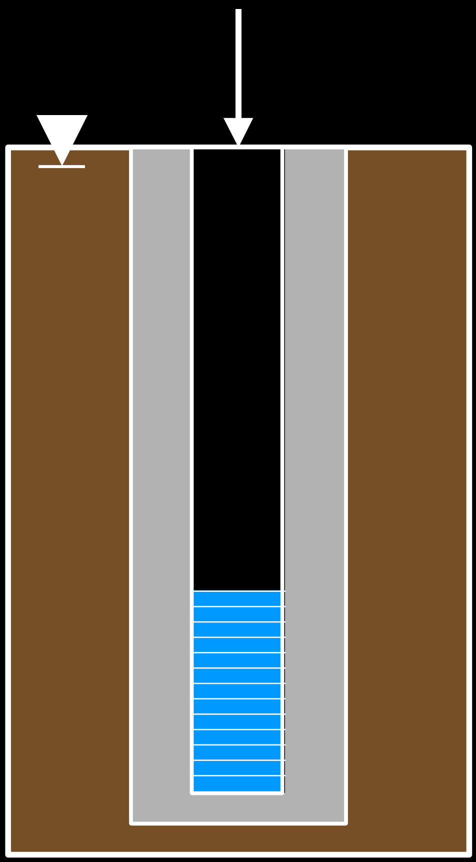
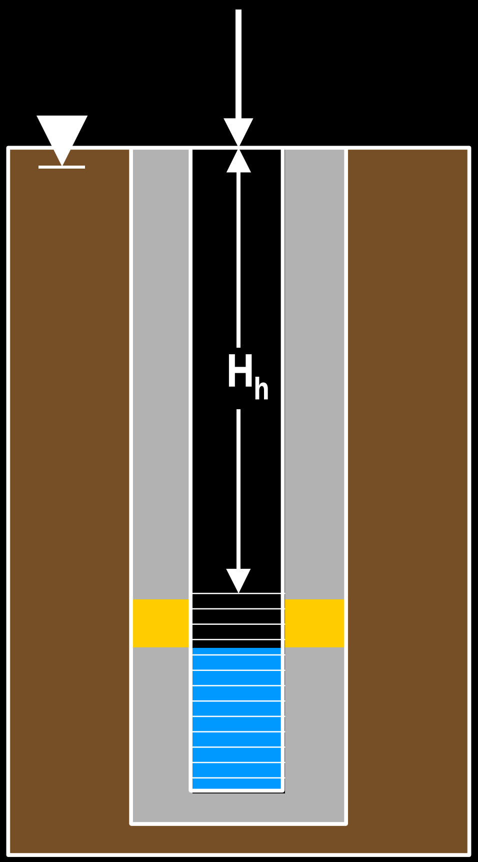
Conceptual Model

$P_G = \rho g H_h$



$P_G = \rho g H_h + P^P$ entry



P_G	=	gauge pressure
r	=	1.0 g/cm^3
g	=	980 cm/s^2
H_h	=	hydrostatic head
P^p_{entry}	=	air entry pressure of packing

Air Injection

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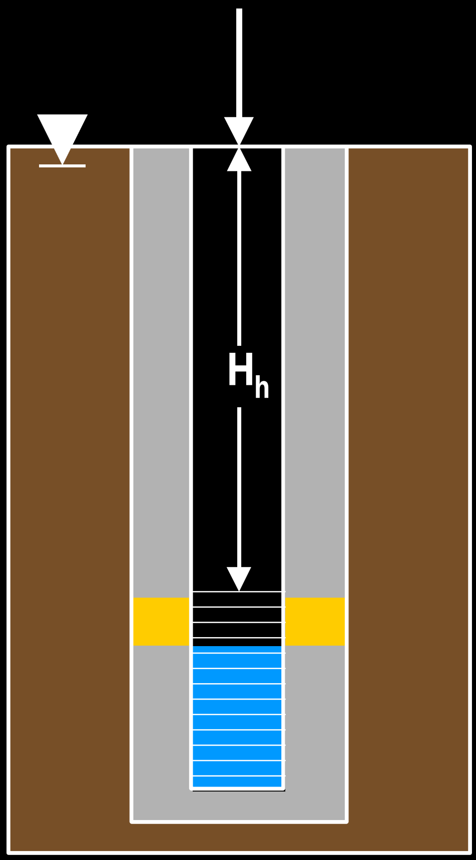
Principles of Air Sparging

- Conceptual model used to described air flow
  - ① When air is injected into well, standing water in well bore is displaced downward and through well screen until air/water interface reaches top of well screen
  - ② For injected air to penetrate aquifer, air pressure in excess of hydrostatic pressure is necessary
    - – excess pressure = air entry pressure of packing
  - ③ Finally, pressure must exceed air entry pressure of formation
    - – minimum capillary pressure needed to induce air flow into a saturated porous medium

Conceptual Model

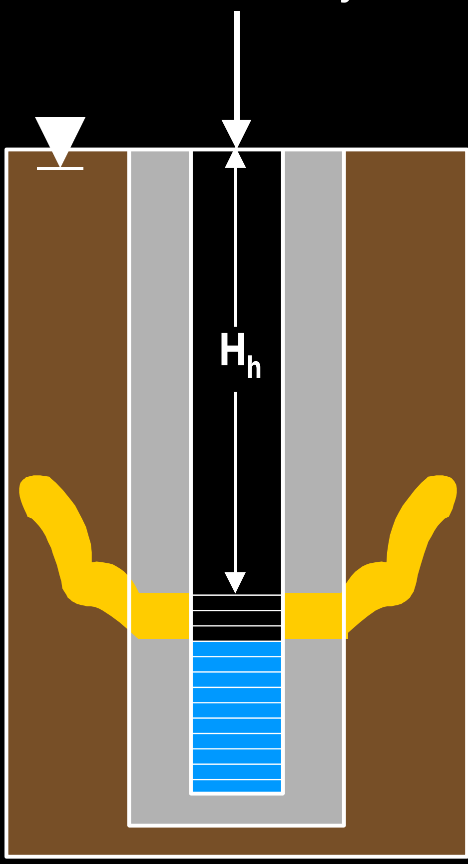
$P_G = \rho g H_h + P^P \text{ entry}$



P_G	=	gauge pressure
ρ	=	1.0 g/cm^3
g	=	980 cm/s^2
H_h	=	hydrostatic head
P^p_{entry}	=	air entry pressure of packing
P^F_{entry}	=	air entry pressure of formation

Air Injection

$P_G = \rho g H_h + P^p_{entry} + P^F_{entry}$



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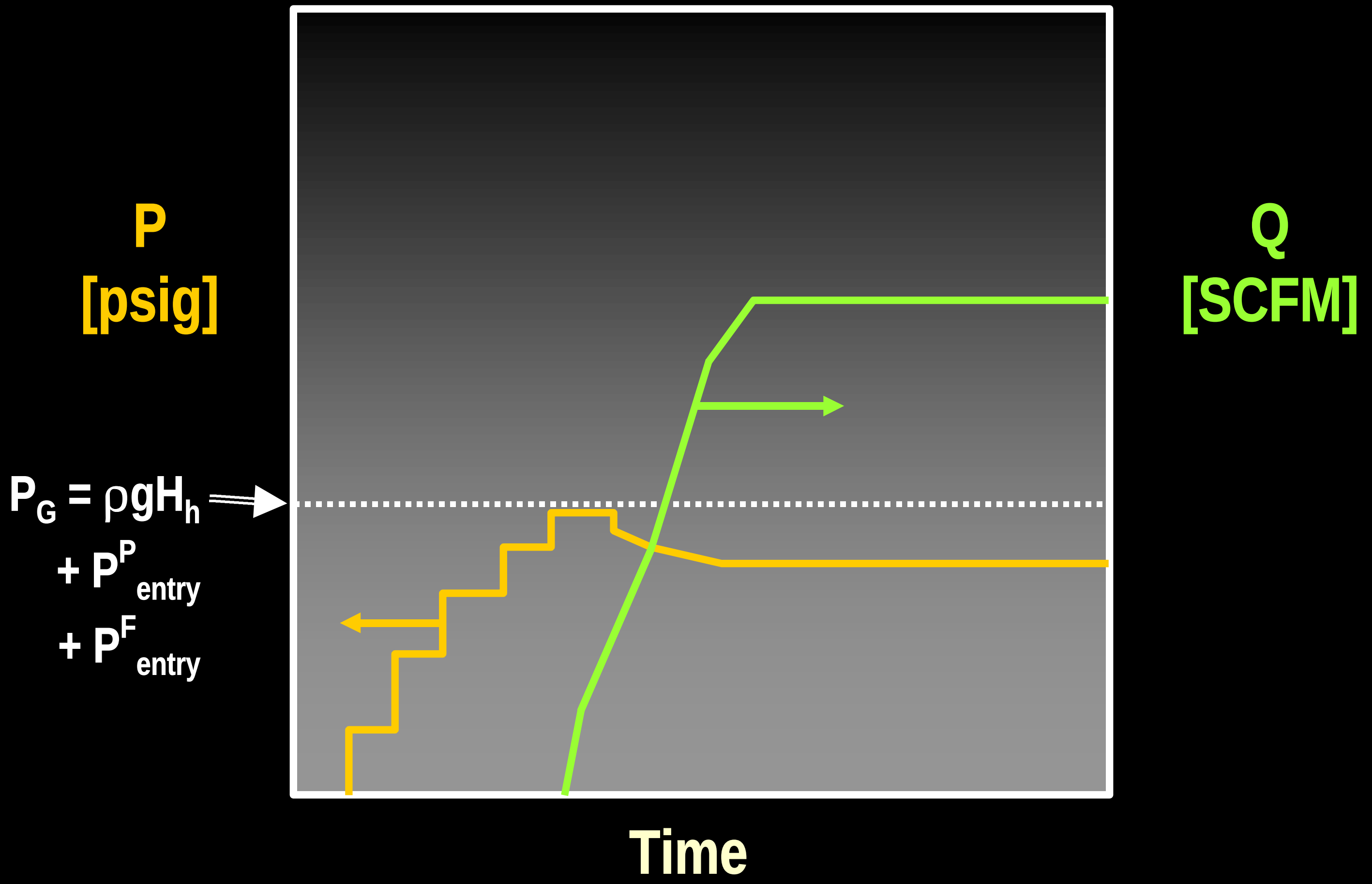
Pressure vs Flow



Principles of Air Sparging

- Previously, idealized version of air bubbles forming during air sparging, with relatively homogeneous distribution around injection well
- Virtually impossible to predict flow path of air channels in real field settings
- Water displacement by air is extremely sensitive to small changes in soil structure

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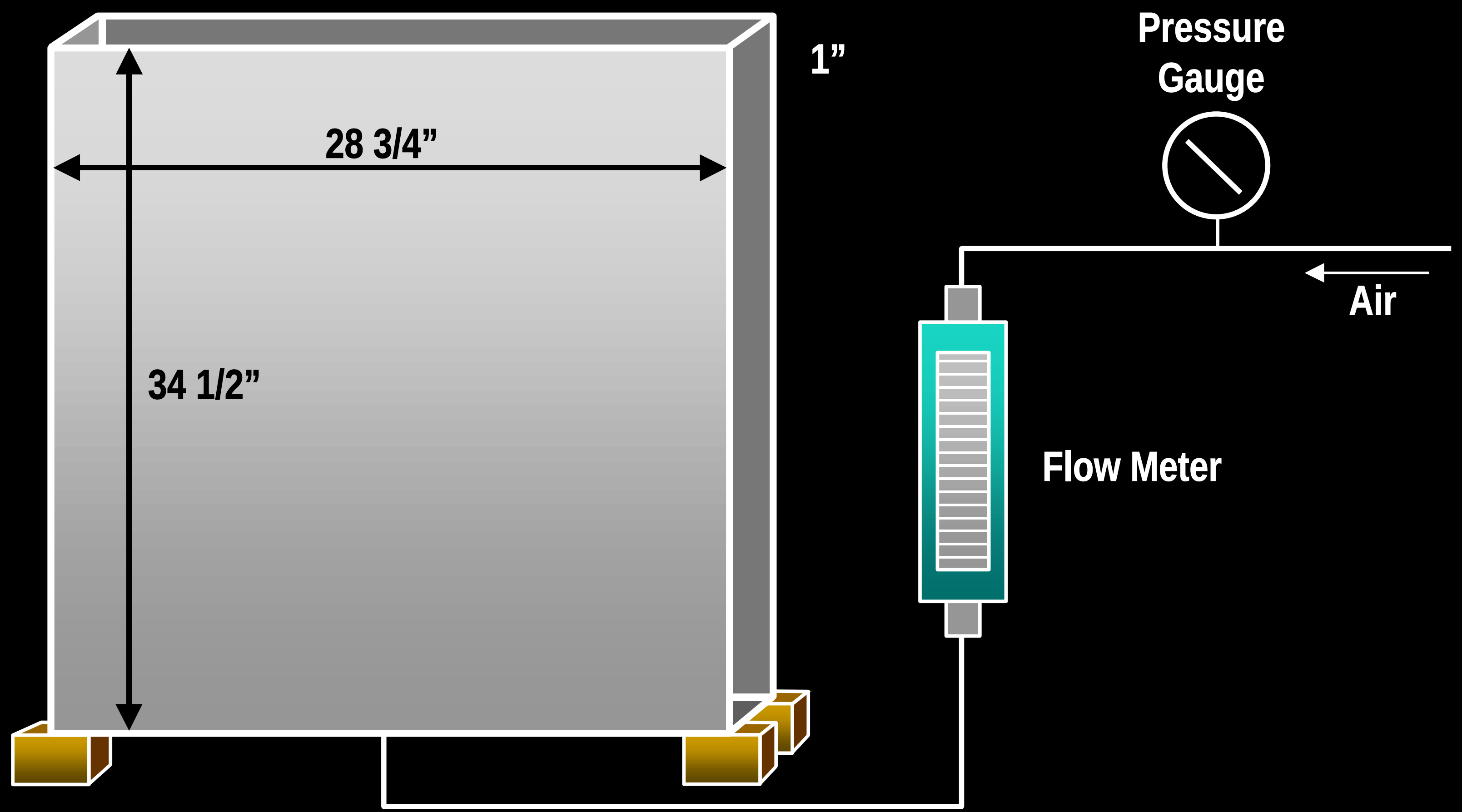
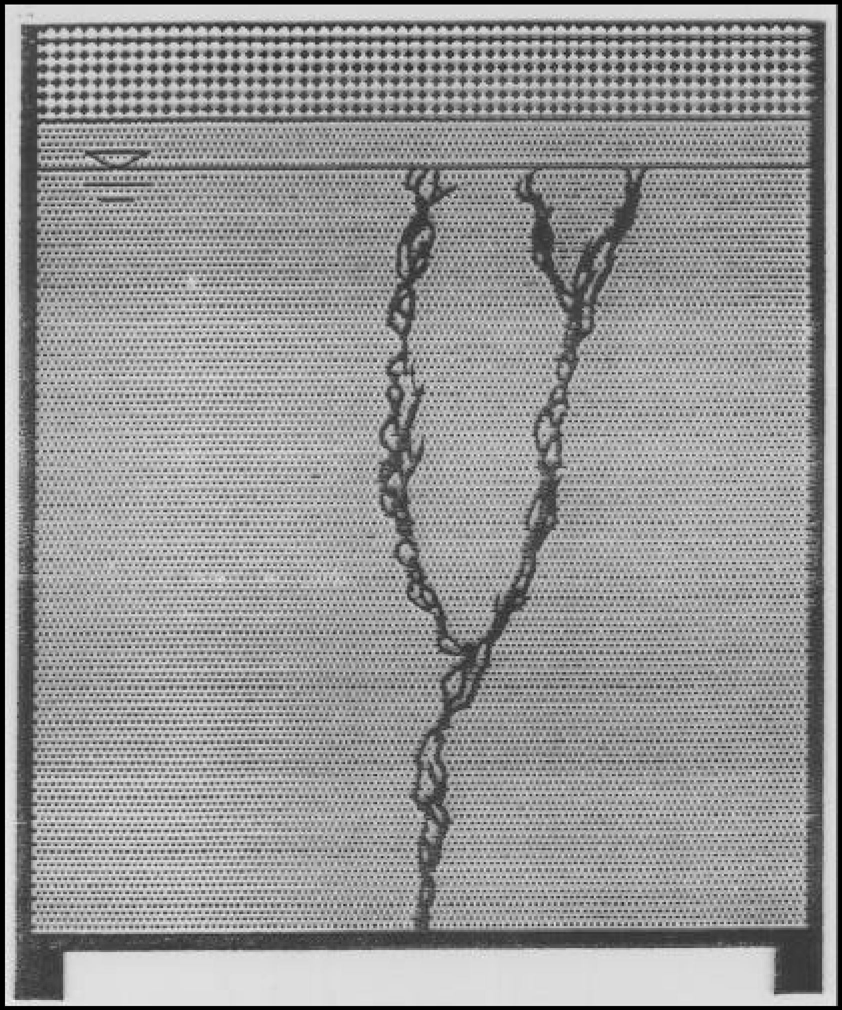
Flow Visualization Studies



Ji et al. (1993). Ground Water Monitoring and Remediation

Low Air Injection Rate, 0.75 mm Glass Beads



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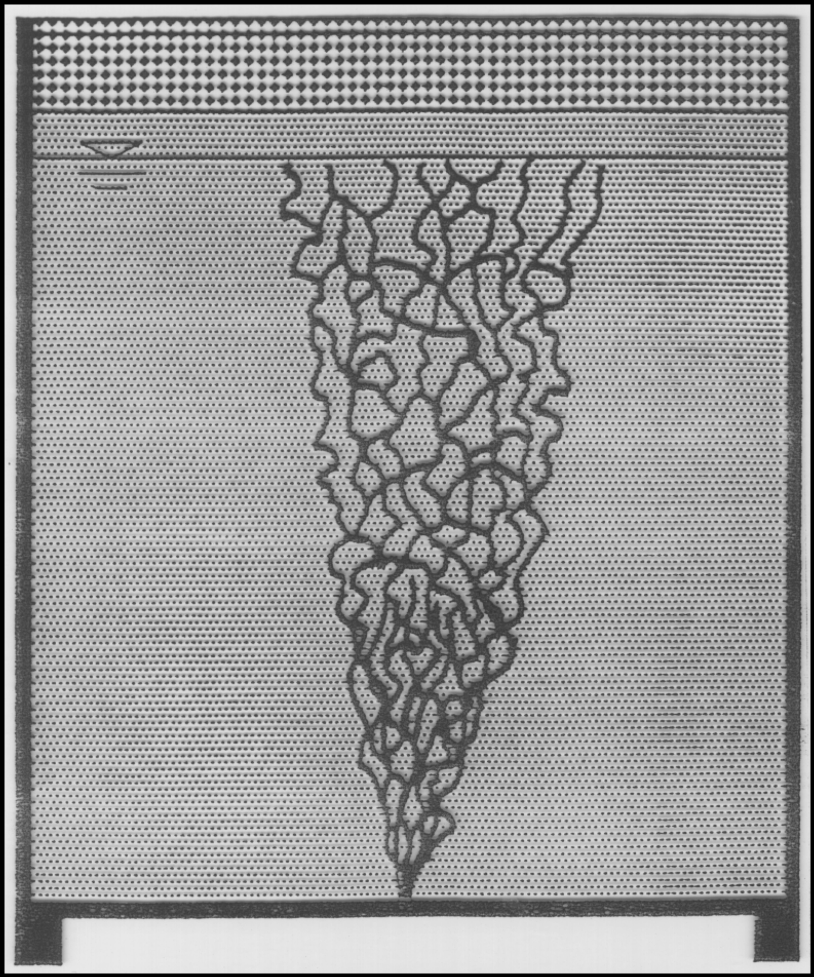
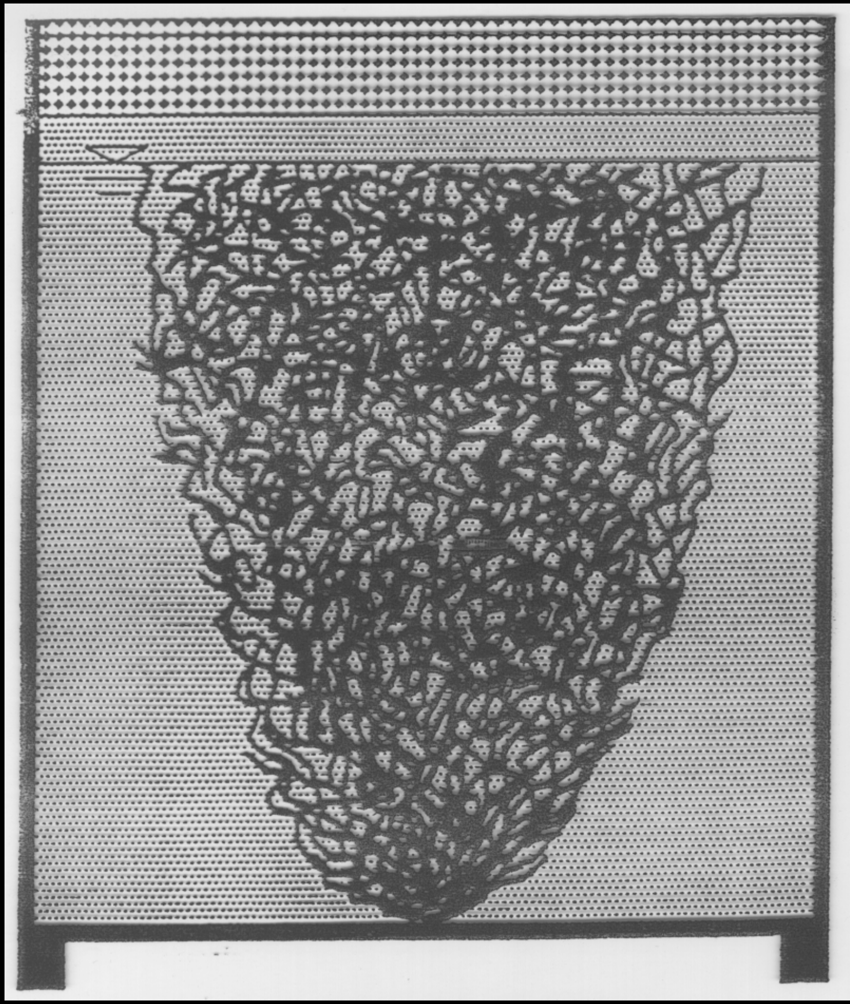
Moderate Air Injection Rate, 0.75 mm Glass Beads



High Air Injection Rate, 0.75 mm Glass Beads



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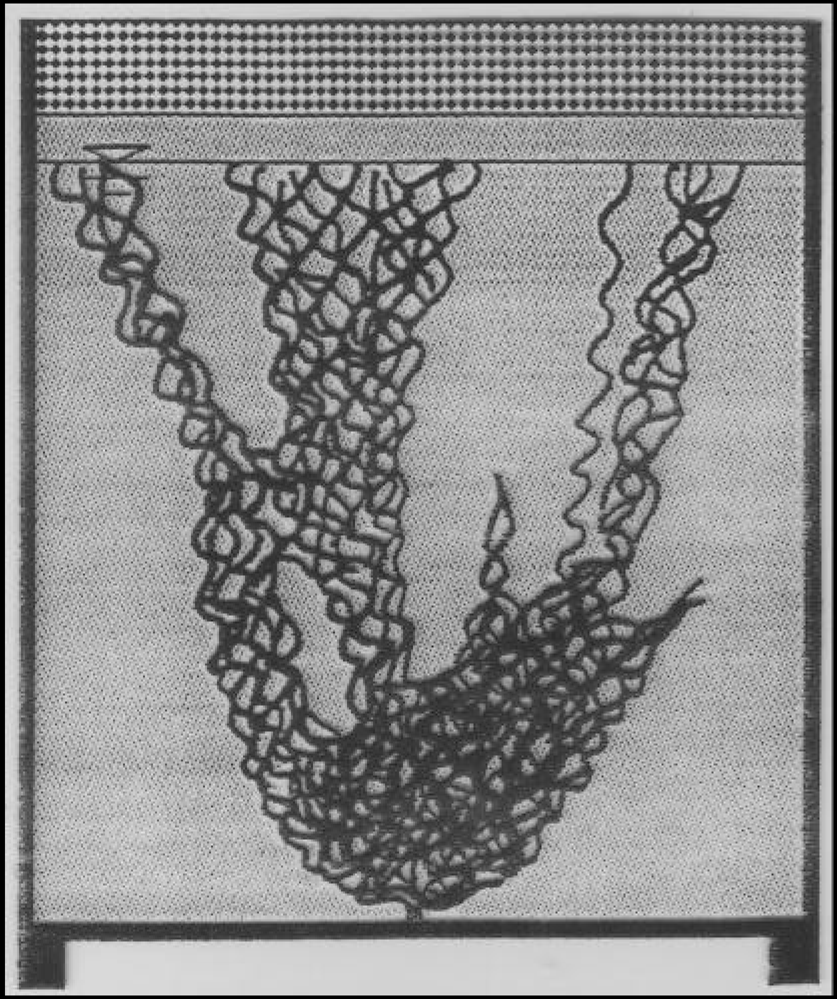
Moderate Air Injection Rate, 38% 0.75 mm Glass Beads, 62% 0.30 mm Glass Beads



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Topics Covered

- What is air sparging?
- How does air sparging work?
- **Implementing air sparging**
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Site Characterization Activities

- Review existing site data and history
- Hydrogeology characteristics

Review of Existing Data and Site History

- Type of contaminant
  - Compound must be either aerobically biodegradable or volatile
    - Compounds with Henry's Law Constants of 10^5 atm-m^3/mole or greater
    - In general, the more soluble a contaminant is in water, the greater the difficulty there is in using air sparging
    - Petroleum hydrocarbons, MTBE, chlorinated solvents are all amenable to removal via air sparging

Review of Existing Data and Site History (cont'd)

- 3-d distribution of contaminant
- Source location - continuing contamination?
- Surface features such as concrete or asphalt
  - May result in higher costs if subsurface installations are required

Hydrogeology Characteristics

- Depth to groundwater
  - Once depth exceeds suction lift (~25 ft), costs increase due to need for traditional wells to allow for submersible pumps for sample collection
- Identify degree of stratification in saturated zone
  - Highly stratified soils may make air sparging design more difficult and more costly
- Air sparging may still be best option even if hydrogeology appears unfavorable - pilot study and cost analysis is essential

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Pilot Tests – State of the Practice

- Given our current limited understanding of the process, it is not clear how to conduct pilot tests such that one can assess the feasibility, or long-term performance, of a given system.
- Thus, at this point in time, pilot tests are actually designed to assess “infeasibility” – that is to say, we try to identify if conditions exist for which we know the process likely will not achieve our goals.
- Beyond this, if one decides to implement air sparging, then they have accepted the risk, or uncertainty, of unknown long-term performance.

Pilot Testing Questions

- Can you inject air into the aquifer at a reasonable air flowrate and pressure?
- Is air distribution relatively homogenous?
- Is it safe?

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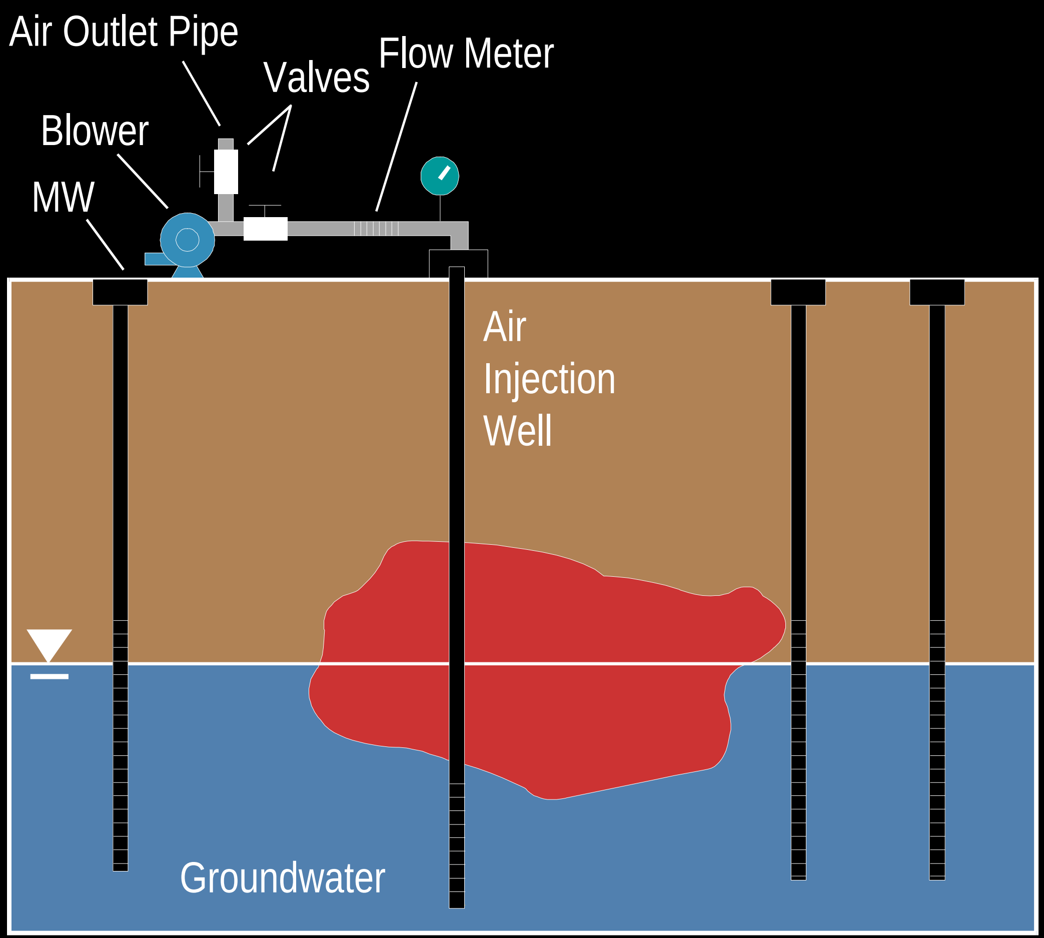
Pilot Testing

Conventional Set-Up

- 1-week duration
- Air injection pressure and flowrate
- Dissolved oxygen levels in groundwater
- Groundwater “elevations”
- Vadose zone pressure changes
- Vadose zone concentration changes
- Extracted vapor concentrations



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Pilot Tests – Objectives and Uncertainty

Air Flowrates & Pressures

- Blower requirements
  - Measure air flow vs. pressure behavior during pilot test
  - High degree of certainty

Air Distribution

- Dissolved oxygen
  - Monitor DO in wells and discrete interval samplers
  - High degree of certainty - may have to wait several days to see effects other than direct channeling
- Tracer testing

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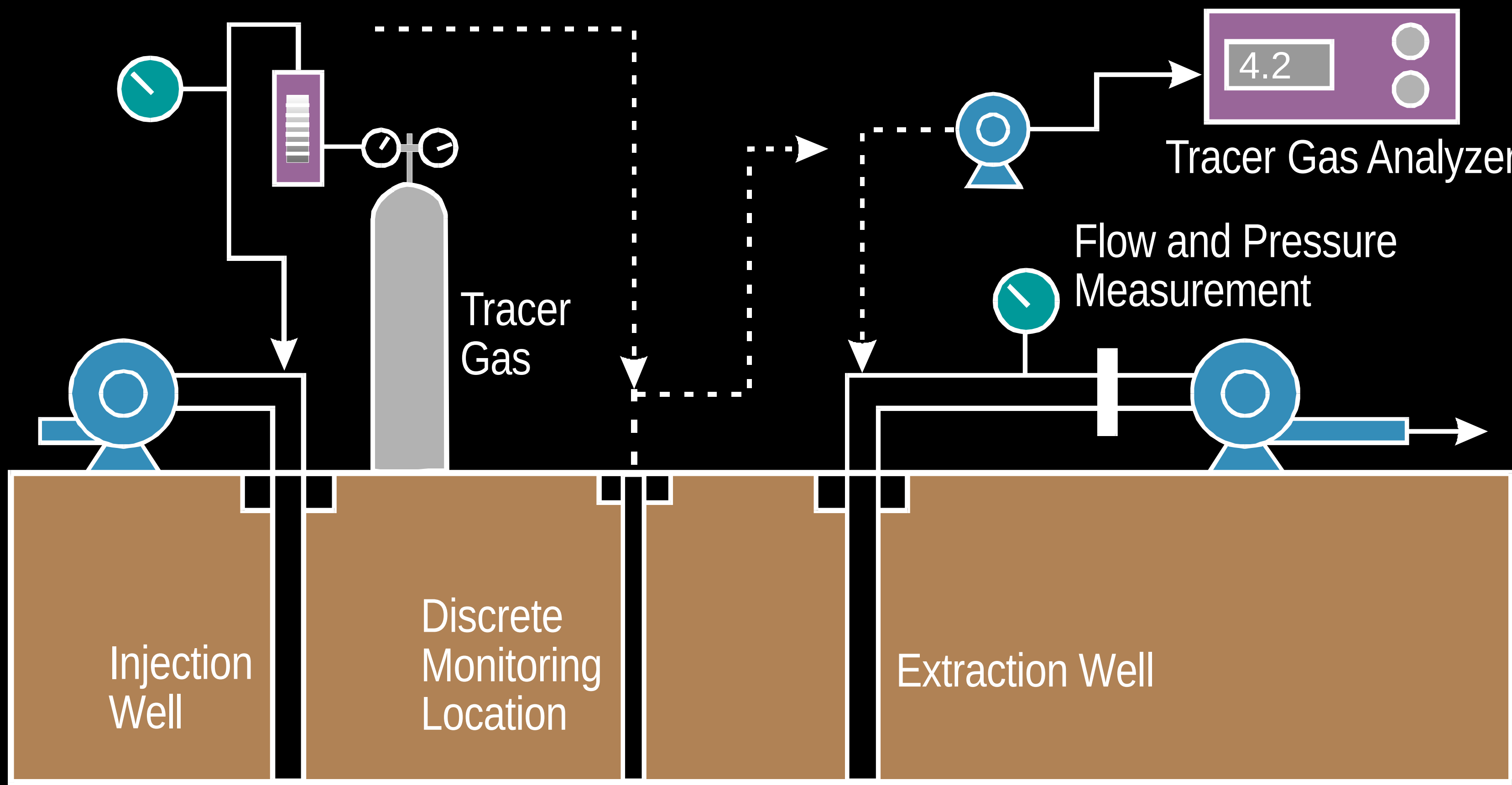
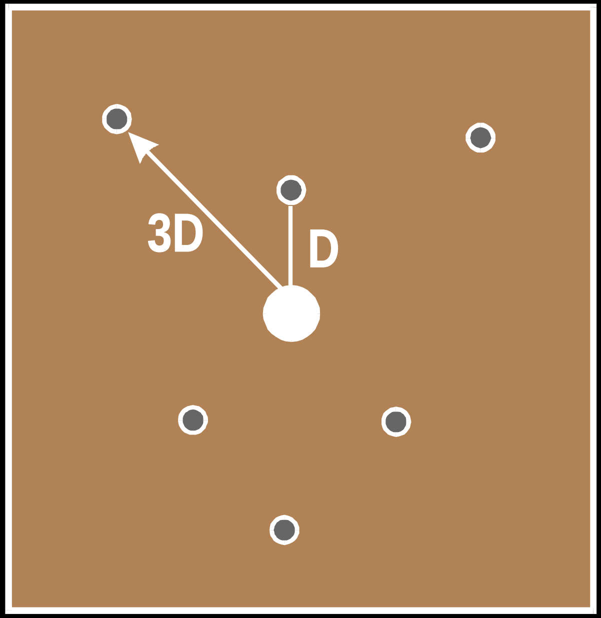
Pilot Testing: Tracer Gas Tests

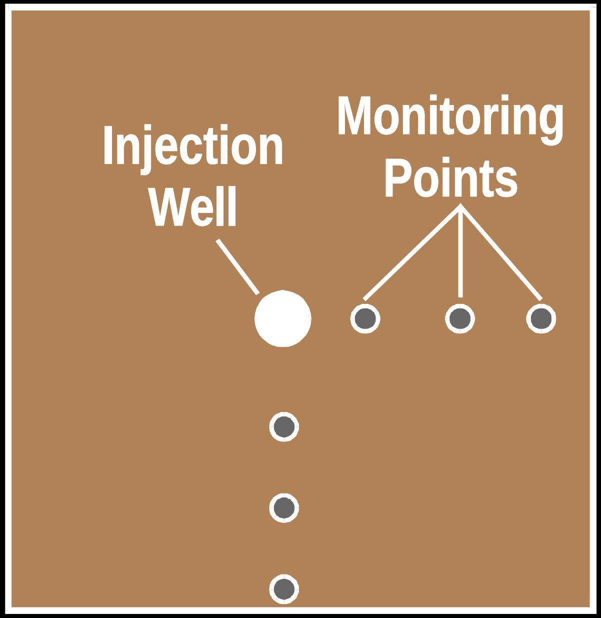


Pilot Testing

Monitoring Point Placement

Monitoring points should be placed around the injection point as air distributions are expected to rarely be symmetrical





D = depth below groundwater to top of injection well screen

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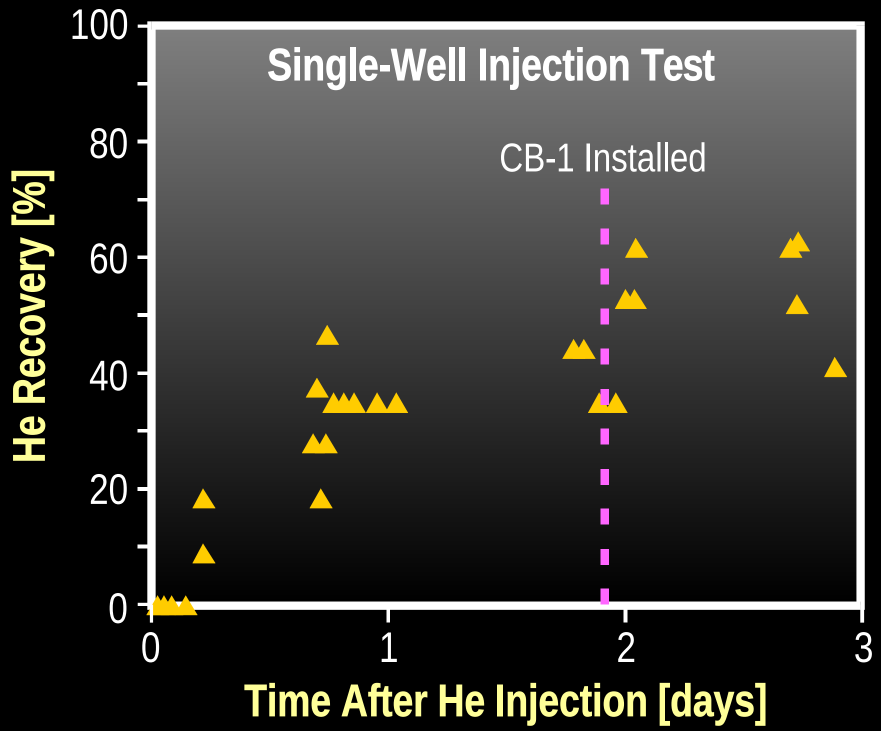
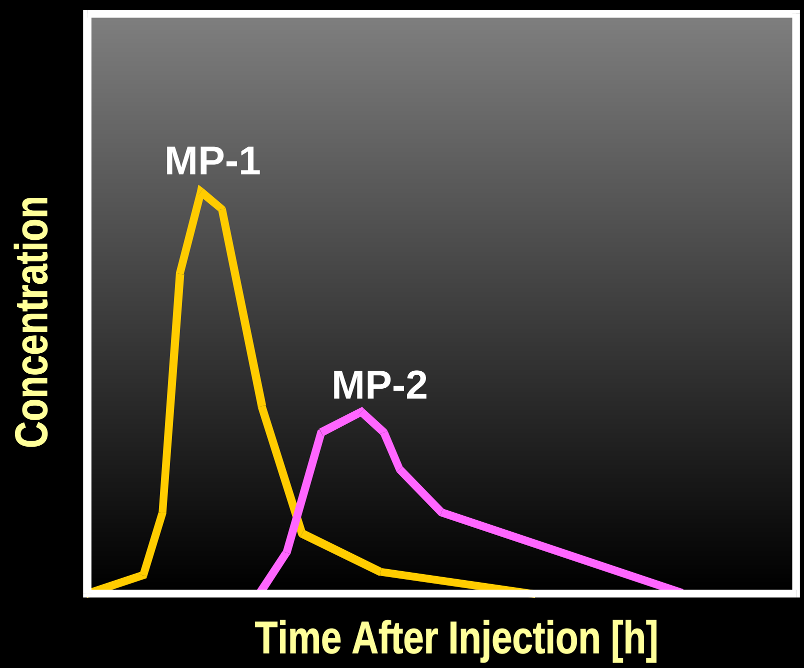
Pilot Testing

Continuous Injection Test



Pulsed Injection Test



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Pilot Tests – Objectives & Uncertainty

Safety/Adverse Impacts:

- Look for vapor migration to sensitive receptors
- Can use tracer gases (e.g., helium)
- Perform vapor recovery tests
- High degree of certainty – but may need to conduct test for about a week …

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Other Measurements Taken During Pilot Testing

- Degree of Volatilization/Oxygenation (Biodegradation)
  - Perform tracer gas studies and push/pull tests
  - Low degree of certainty – volatilization rates affected by vadose zone processes and efficiency of vapor capture system
- Optimal Air Injection Rates
  - Measure changes in dissolved oxygen levels, volatilization rates, and other performance indicators as functions of air flow
  - Low degree of certainty – difficult to assess within a 1- to 2-week timeframe, best to use standard practice initially (pulsed injection, ~15 scfm) & optimize over time

Other Measurements Taken During Pilot Testing (cont.)

- Contaminant Removal
  - Measure contaminant vapor concentrations in extracted vapors
  - Measure increases in vadose zone vapor concentrations
  - Measure decreases in dissolved levels
  - Degree of certainty is medium – may have to wait several weeks to get accurate assessment; vapor data may be confounded with vadose zone volatilization

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Pilot Testing Questions

- Can you inject air into the aquifer at a reasonable air flowrate and pressure?
  - Injection pressure too high (e.g., exceeds soil overburden, or 150% of calculated value, etc.)
- Is air distribution relatively homogeneous?
  - i.e., flow field is highly asymmetrical (air flow has strong tendency toward flow in one direction)
- Is it safe?
  - i.e., air injection causes adverse impacts (e.g., enhanced contaminant migration, vapor problems, etc.)

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- How does air sparging work?
- **Implementing air sparging**
  - Site characterization
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  - **Field design**
  - Process monitoring & site closure
- Cleanup times and costs
- Examples: Port Hueneme, CA and DODHF Novato, CA
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Air Sparging Design

- **Overview**
- Design approach
- Number of extraction wells
- Injection well construction
- Blower selection
- Monitoring point construction

Air Sparging Design

- Should I add microorganisms?
  - NO!!
- Should I enumerate or count microorganisms?
  - Probably not...
    - Many enumerations have been done and generated little useful data
    - Identity of bugs may be of academic curiosity, but of little engineering value

Air Sparging Design

- Are nutrients required?
  - Usually not ...
    - Compare oxygen utilization rates to literature. Only consider nutrient addition if rates are consistently low and contamination is high
    - Be wary of laboratory-scale tests (do not correlate well with field results)

Why Don’t Nutrients Help?

- Low microbial activity
- Nutrient recycling
- Difficulty in nutrient addition in situ
  - hard to apply uniformly
  - expensive

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Air Sparging Design

- Overview
- **Design approach**
- Number of extraction wells
- Injection well construction
- Blower selection
- Monitoring point construction

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Air Sparging Design

- Two approaches
  - Standard design
  - Site-specific design
- Due to uncertainty of long-term efficiency of an air sparging system, it is more cost-effective to use a standard design rather than spend much time and money on detailed pilot tests
- For very large or very deep sites, more detailed pilot tests (site-specific design) are warranted to ultimately reduce costs
- Therefore, selection of approach based primarily on cost

Design Approach (cont.)

- Petroleum hydrocarbon-contaminated sites
  - Use air sparging to treat source zone
  - Often, natural attenuation is sufficient for plume
  - An air sparging curtain can be used to prevent further migration of plume if necessary
- Chlorinated solvent-contaminated sites
  - Use air sparging to treat contaminated plume
  - Source zones are often difficult to locate

Air Sparging Standard Design

- Sparge wells installed on a 15-ft spacing
  - Assumes a small radius of influence, which is not unusual during air sparging
- Air injection rate of 5 to 20 scfm
- Pulsed injection (~3 hours on, 3 hours off)

Air Sparging Site-Specific Design

- Conduct more detailed tracer testing to determine a specific zone of influence
  - In order to base system design on a large radius of influence, one must be confident about air distribution
  - Determine air distribution at significant distances from sparge well
  - Determine air distribution radially around sparge well

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Air Sparging Design

- Overview
- Design approach
- **Number of extraction wells**
- Injection well construction
- Blower selection
- Monitoring point construction

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Extraction wells

- Extraction wells are useful for monitoring mass removal via volatilization
- Vapor recovery often is not necessary due to the biodegradative capacity of the vadose zone
- Necessity of vapor recovery determined during pilot testing (is it safe?)

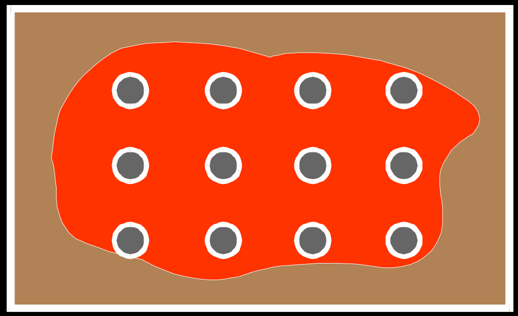
Extraction Wells

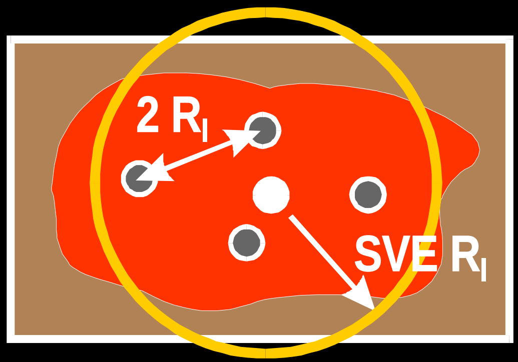
Three approaches are commonly used to select the number and location of vapor extraction wells*:

1. Install vapor extraction well at each air injection well placement (i.e., dual completion wells)

2. Base well spacing on results of pilot test vacuum data

3. Use existing SVE/Monitoring wells





* This guidance is specific to vertical wells.

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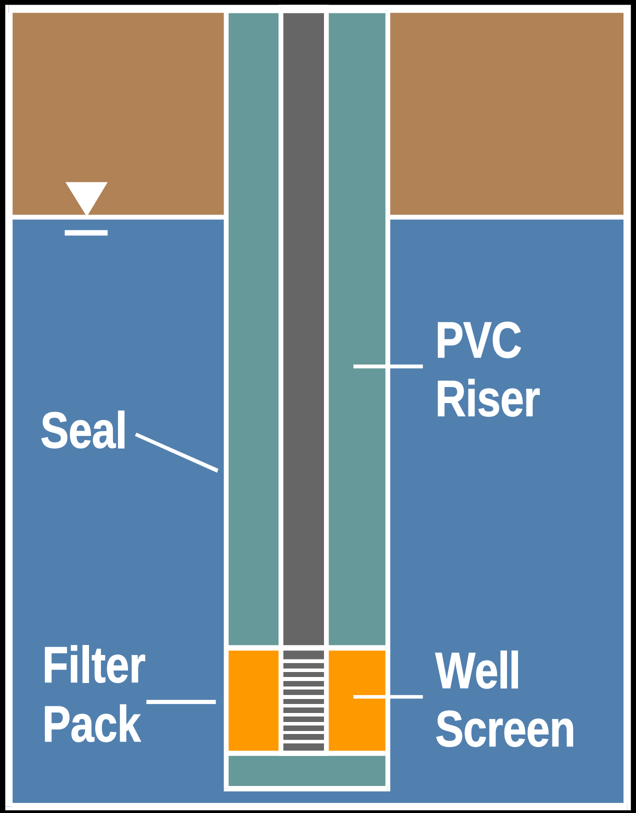
Air Sparging Design

- Overview
- Design approach
- Number of extraction wells
- **Injection well construction**
- Blower selection
- Monitoring point construction

Injection Well Construction

- Direct push is preferable installation method
- Traditional installation necessary at deeper depths (>~25 ft)
- PVC is typical well material
- Well screen is generally 2 ft long



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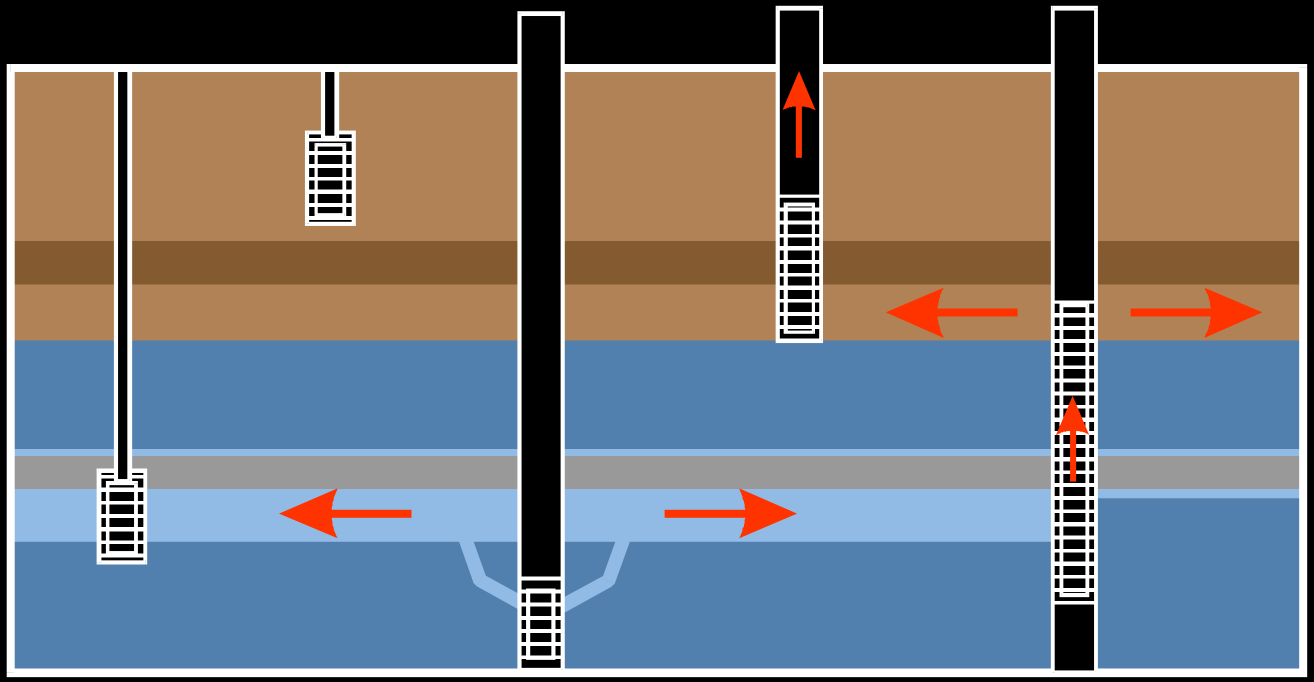
Injection Well Construction



1. Injection point is generally 5-10 ft. below zone of contamination
2. Effect of stratigraphy on air flow paths should be reviewed prior to specifying injection depth

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Air Sparging Design

- Overview
- Design approach
- Number of extraction wells
- Injection well construction
- **Blower selection**
- Monitoring point construction

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Blower/Compressor Selection

1. Blower should be able to supply ≈ 5-20 ft^3/min per sparge point at a pressure in the range of:

   $0.4*H_{well} \le P \le 0.4*H_{well} + 0.7*H_{soil}$ [psig],

   Hwell = height of water displaced [ft]

   Hsoil = depth to injection point [ft BGS]

2. Oil-less compressors are preferred
3. Regenerative blowers good up to about 10 psig; above that, reciprocating compressors or rotary lobe blowers may be required
4. Noise abatement may be necessary …

Estimating Minimum Pressure Required

Typically, $H_h \geq 5$ ft H_2O, so in most cases:

$H_h > P^F{}_{entry}/\rho g > P^P{}_{entry}/\rho g$, and therefore

$P_{min} \approx \rho g H_h$

P_G = 1 atm = 407 H_2O = 33.9 ft H_2O = 14.7 psig

0.43 psig per ft of H_2O head

Air Sparging Design

- Overview
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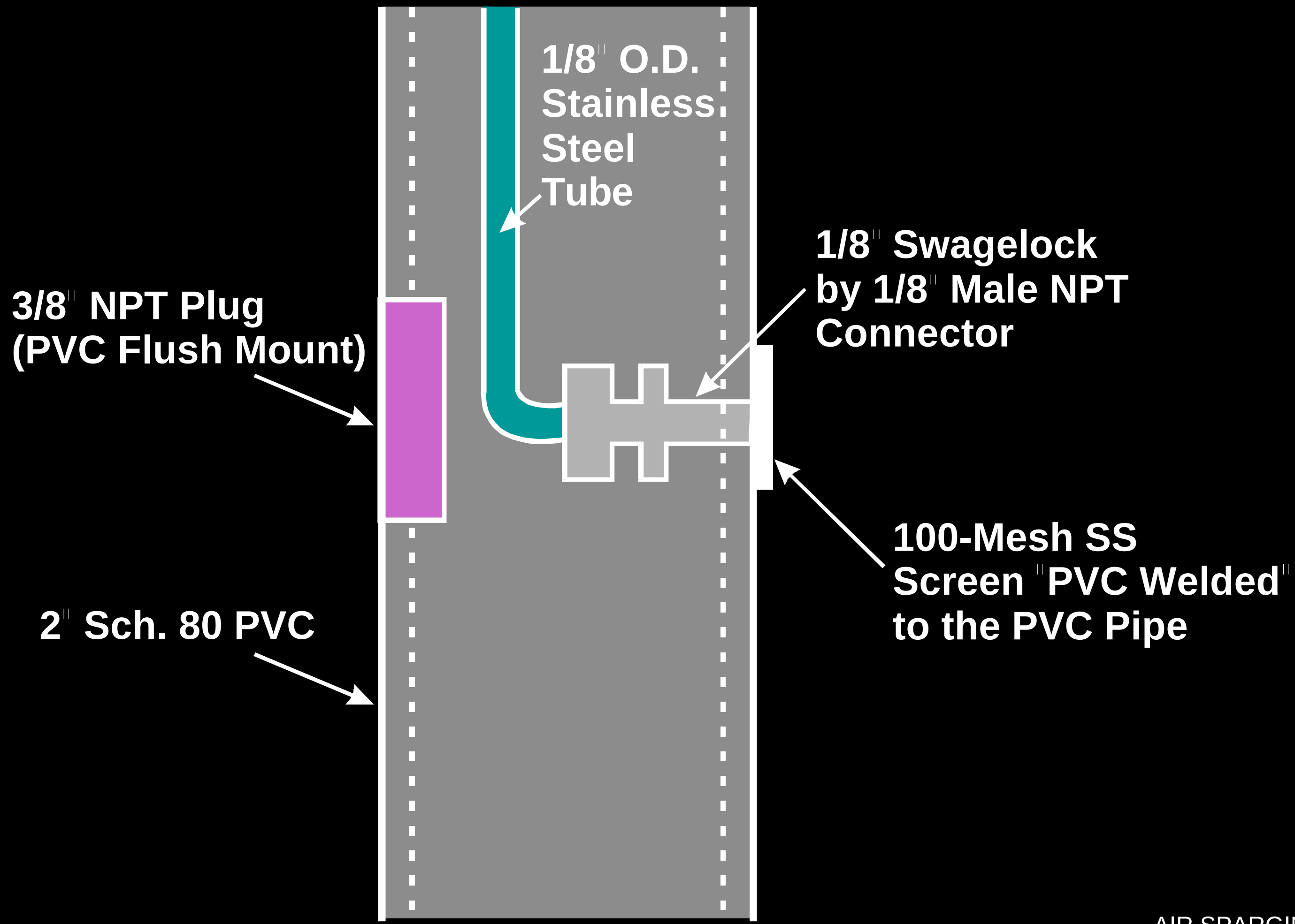
- **Monitoring point construction**

Monitoring Point Construction

- Monitoring points necessary for tracer testing and process monitoring
- Number of monitoring points an economic and scope decision
  - Research-oriented projects will require more monitoring points
- Discrete sampling interval is essential

Cross-Section of Single Sampling Point in Multi-Level Sampler



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Monitoring Point Construction

- Position considering air distribution/tracer testing
  - Minimum 6 locations from sparge well
- Minimum of 2 depths
  - Vadose zone sampling interval
  - Contaminated portion of aquifer
    - With petroleum contamination, contaminated zone is typically narrow and one sampling interval may suffice
    - With other contamination, contaminated zone may be much wider and more sampling zones within the aquifer will be necessary

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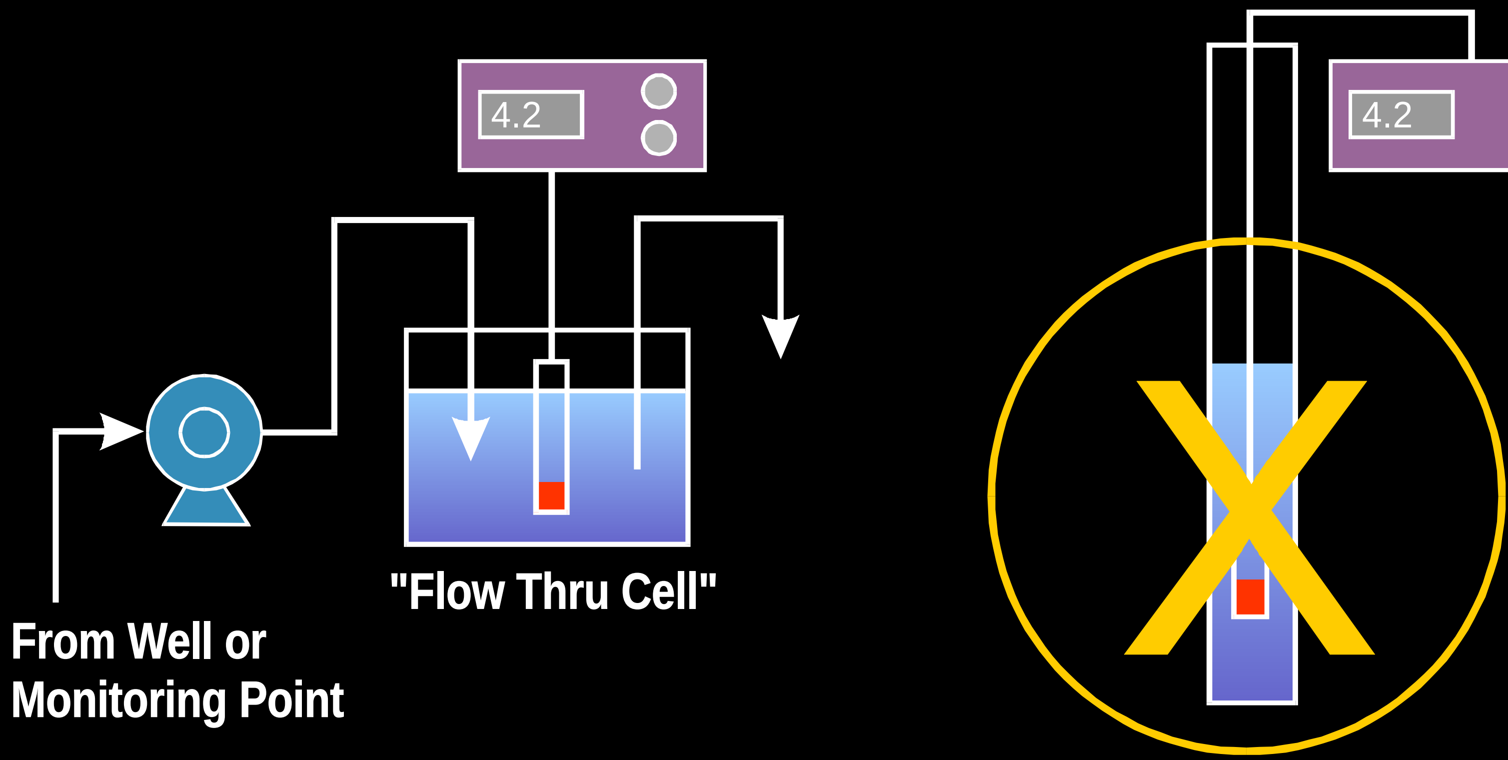
Process Monitoring

- Dissolved oxygen
  - Ensure adequate air distribution
- Groundwater contaminant concentrations (frequency is generally regulatory-driven)
  - Monitor mass removal progress
- Off-gas contaminant concentrations
  - Monitor mass removal via volatilization

Pilot Testing

Dissolved Oxygen (DO) Measurements



Recommended

Not Recommended

Site Closure

- Closure is regulatory-driven
- Typically must meet groundwater cleanup criteria
- Cleanup time typically less than 2 years

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Cleanup Times and Costs are Site Specific

- Hydrogeology characteristics
- Contaminant location and distribution
- Contaminant concentration
- Desired cleanup time
- Air emissions

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Removal Efficiency

Contaminant Type	% Removal	Time (days)
Petroleum Hydrocarbons	80	180
	65	90
	>99	450
Chlorinated Solvents	85	60
	58	120

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Cost Factors to Consider

- Project planning
- Project work plans and submittals
- Regulatory issues and permitting
- Site layout, preparation, mobilization, and demobilization
- System Start-up and performance testing
- Sampling and Analysis
- Long-term performance monitoring

Full-Scale Air Sparging Costs

Task	Total Cost ($)
Site visit/planning	5,000
Work plan preparation	6,000
Pilot testing	40,000
Regulatory approval	6,000
Full-scale construction	
Design	7,500
Drilling/sampling	15,000
Installation/startup	4,000
2-yr monitoring	15,000
2-yr power	2,800
TOTAL	**101,300**

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- Summary

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Air Sparging Effectiveness for Remediation of a Gasoline Plume at Port Hueneme, CA: Participants

Funding Organization	**Strategic Environmental Research & Development Program (SERDP)**
Program Management	**U.S. Air Force Environics Directorate of the Armstrong Laboratory**
Supporting Organization	**U.S. Naval Facilities Engineering Service Center**

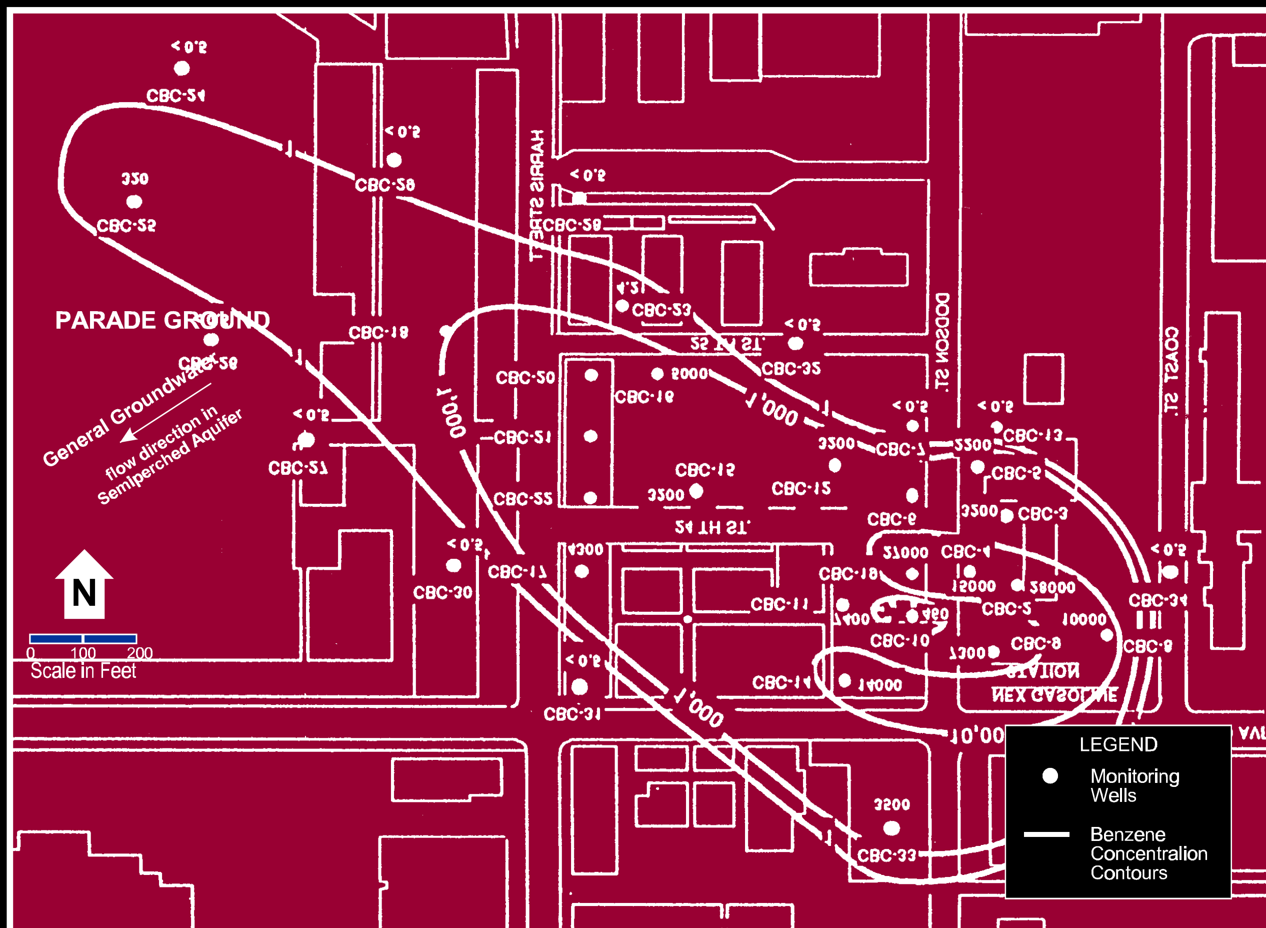
Scope of Work (cont.)

- Conduct air sparging field testing
  - Install two sites within same gasoline plume
  - Site installations identical
  - One site in dissolved phase, one site in source zone
  - Intensive monitoring
- Develop protocol for evaluating application of air sparging

Site Description

- Contaminated with gasoline from underground storage tanks
- Groundwater at ~ 9 to 10 ft bgl
- Site soils fine-grained silty sand from 0 to ~ 6 ft bgl; intermediate fine- to coarse-grained sand from ~ 6 to 24 ft; clay unit at ~ 25 ft

Benzene Plume at the NEX Gas Station, Port Hueneme



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Vertical Distribution of Benzene in Groundwater at Site 1

Depth (ft bgl)	Benzene (µg/L)
10	870
11	4,900
12	160
13	1,900
14	270
15	<15

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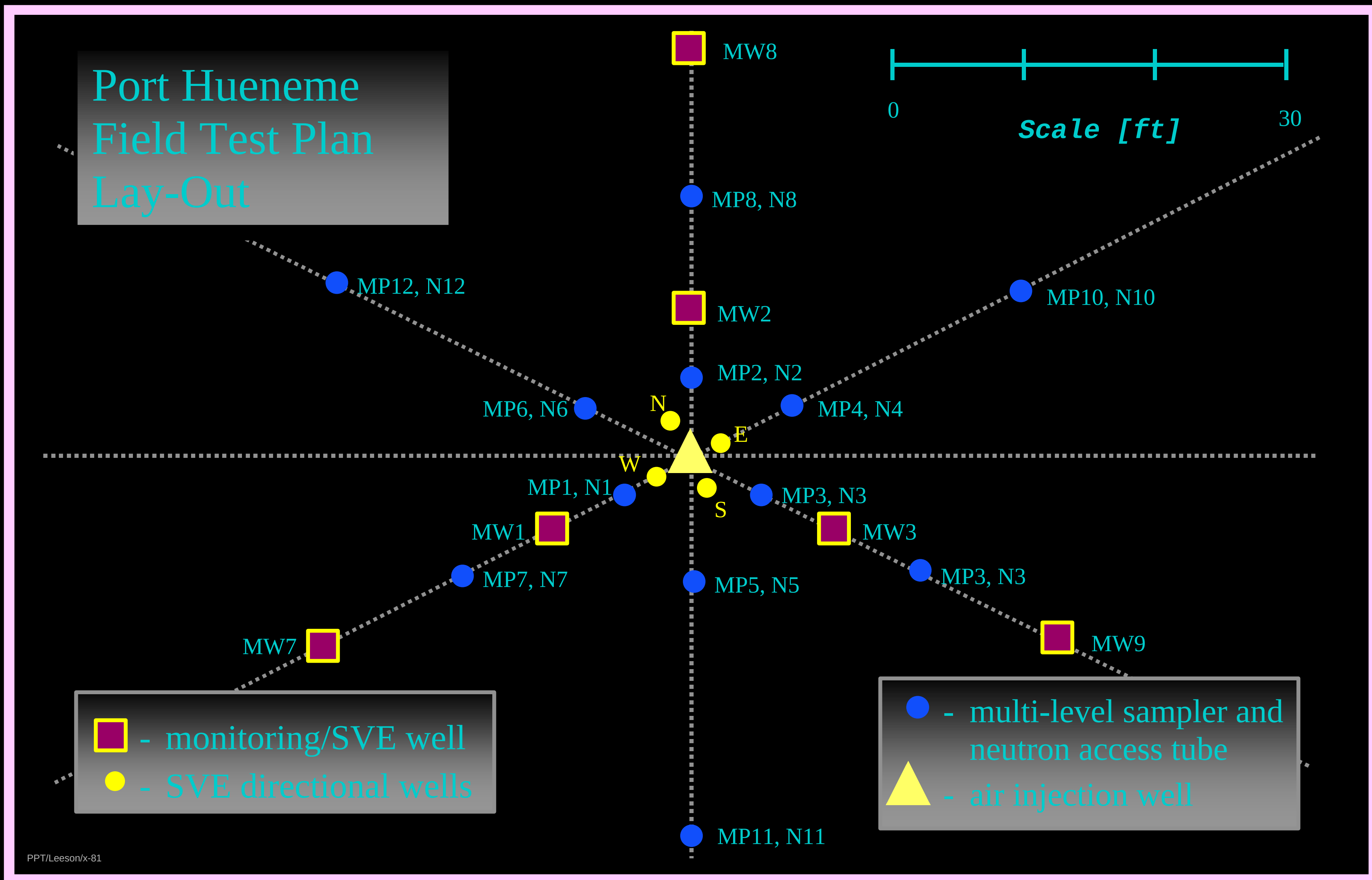
System Installations

- All installations installed by direct push to minimize soil disturbance
- 1 sparge well
  - 2-inch diameter PVC to 20 ft with 2 ft of screen
- 6 conventional monitoring wells
  - Can be used for SVE & also for conventional groundwater contaminant monitoring
- 4 directional SVE wells
  - Conventional SVE wells positioned to measure general quadrant where injected air reaches vadose zone

System Installations (cont.)

- 12 subsurface multi-level samplers
  - 14 sampling ports in each multi-level sampler
  - Sampling ports at 2, 4, 6, 8, 10, 11, 12, 13, 14, 15, 16, 17, 18, and 19 ft bgl
  - Provides intensive monitoring at discrete intervals
  - Used to collect groundwater and soil gas samples, and to collect ERT data
- 12 neutron probe access tubes
  - Used for neutron probe & capacitance probe logging



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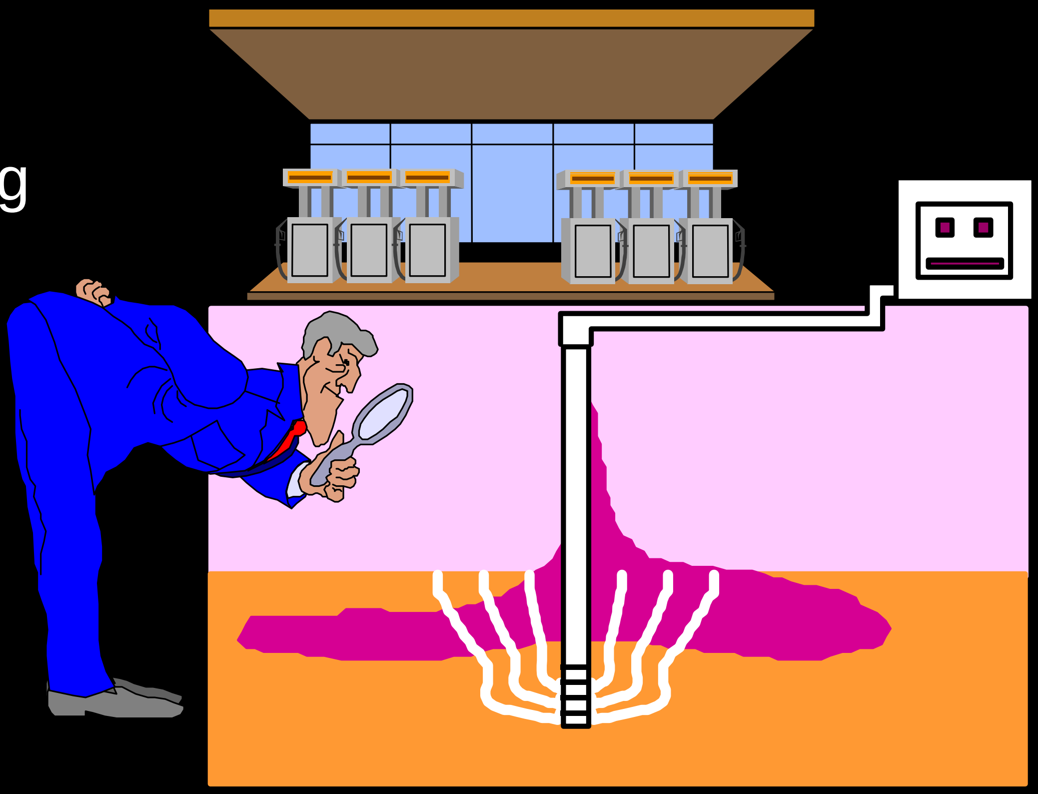
Field Testing

- Assessment of air distribution:
  - Neutron probe logging
  - Capacitance probe
  - ERT
  - Dissolved oxygen
  - Tracer gases



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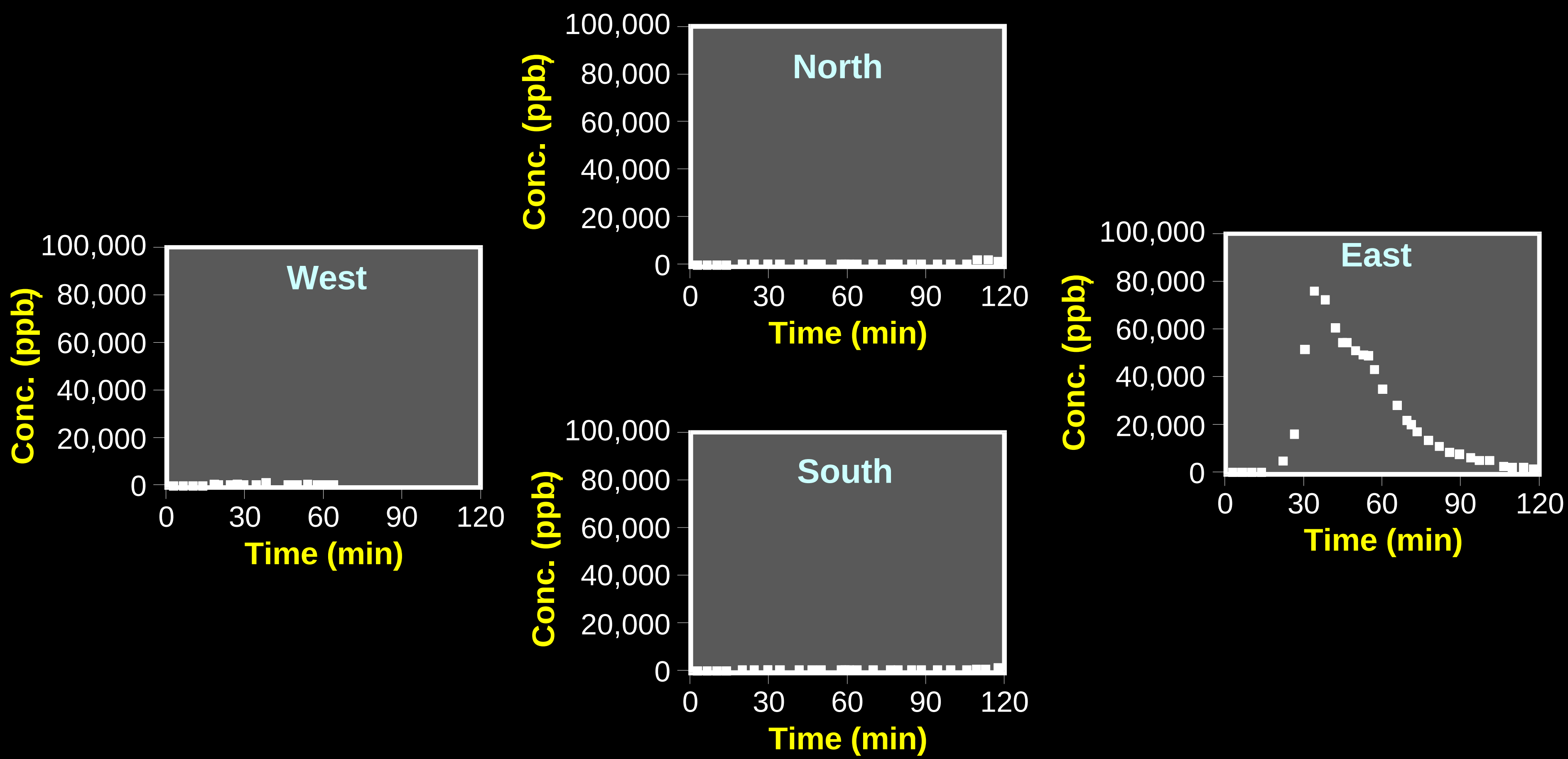
System Monitoring

- Directionality of air flow
  - Tracer testing with tracer injected at discrete intervals of a multi-level sampler or mixed with injection air
- SVE Recovery of Injected Air
  - Helium mixed with injection air to determine efficiency of SVE
- Air distribution in groundwater
  - Measured via dissolved oxygen, tracer testing (SF6), ERT, or neutron probe

Directionality of Air Flow

SVE Well Response to Tracer Injection Into MP4-4.0'



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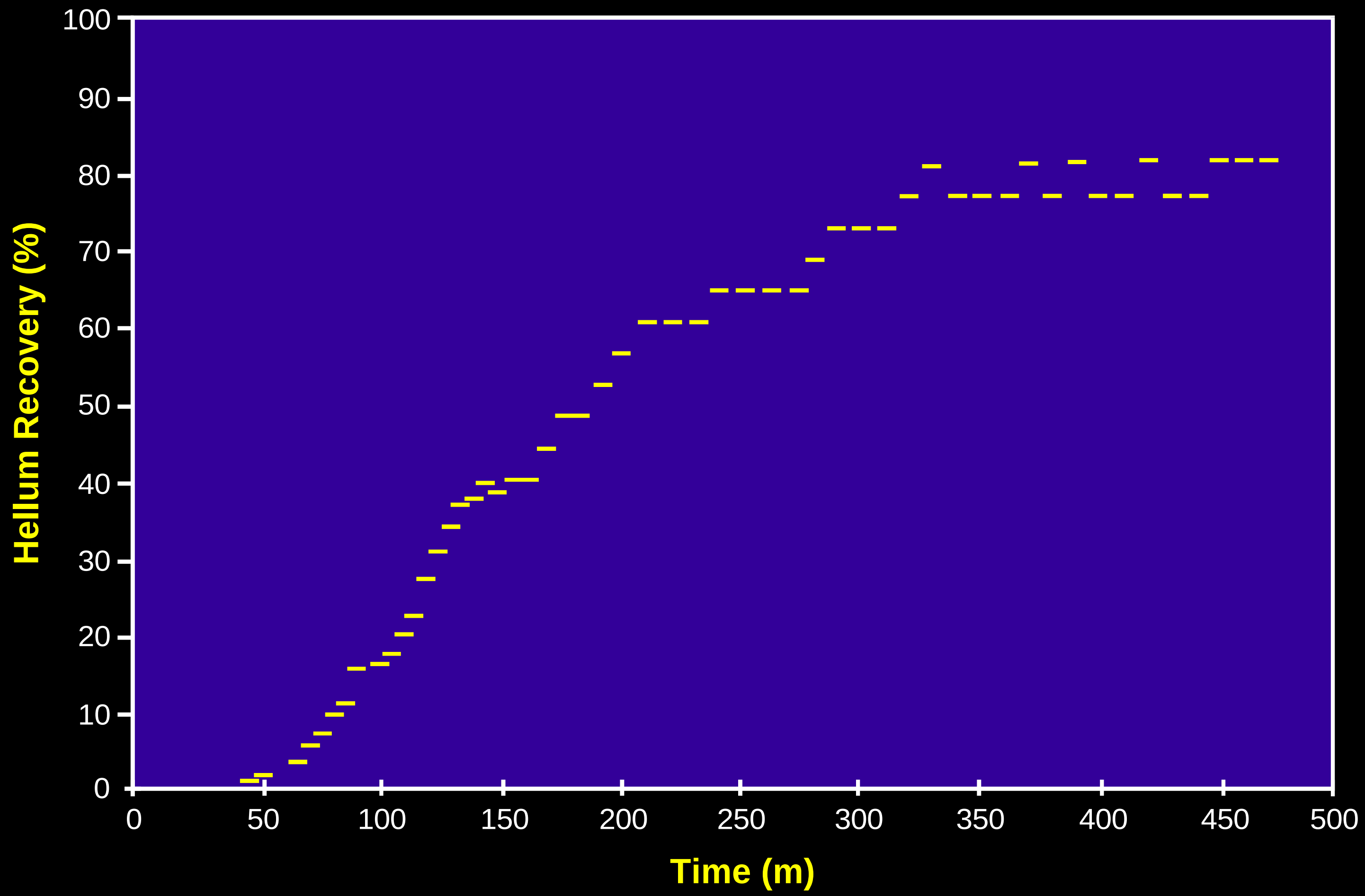
SVE Recovery of Injection Air



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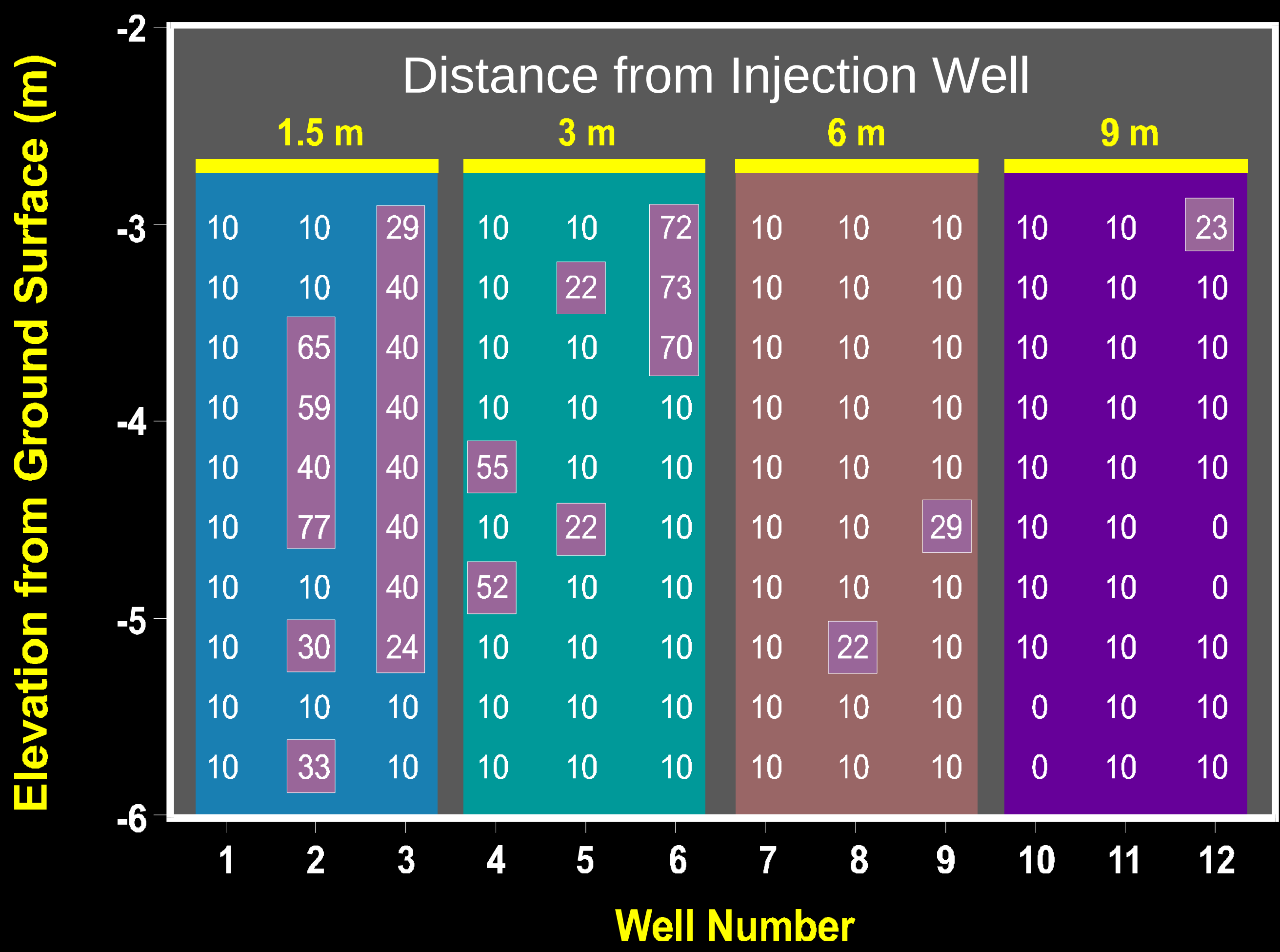
Air Distribution in Groundwater

Dissolved Oxygen Measurements



Preliminary Conclusions

- Air sparging monitoring system is working well as designed (i.e. air appears to be distributed within the outer ring of monitoring points and there is little evidence of significant movement of air outside the monitoring system
- Travel time from injection to extraction indicates most of the air probably reaches the vadose zone ~10 ft from the injection well
- Based on tracer testing, virtually all injected air is captured by the SVE system

UST Remediation Project at Department of Defense Housing Facility, Novato, CA

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Background

- Gasoline release from USTs in 957 and 970 areas
- USTs and associated piping removed
- Dissolved hydrocarbon plumes commingled
- SCAPS and GeoProbe™ investigations
- 9 monitoring wells installed
- Site map with contours produced

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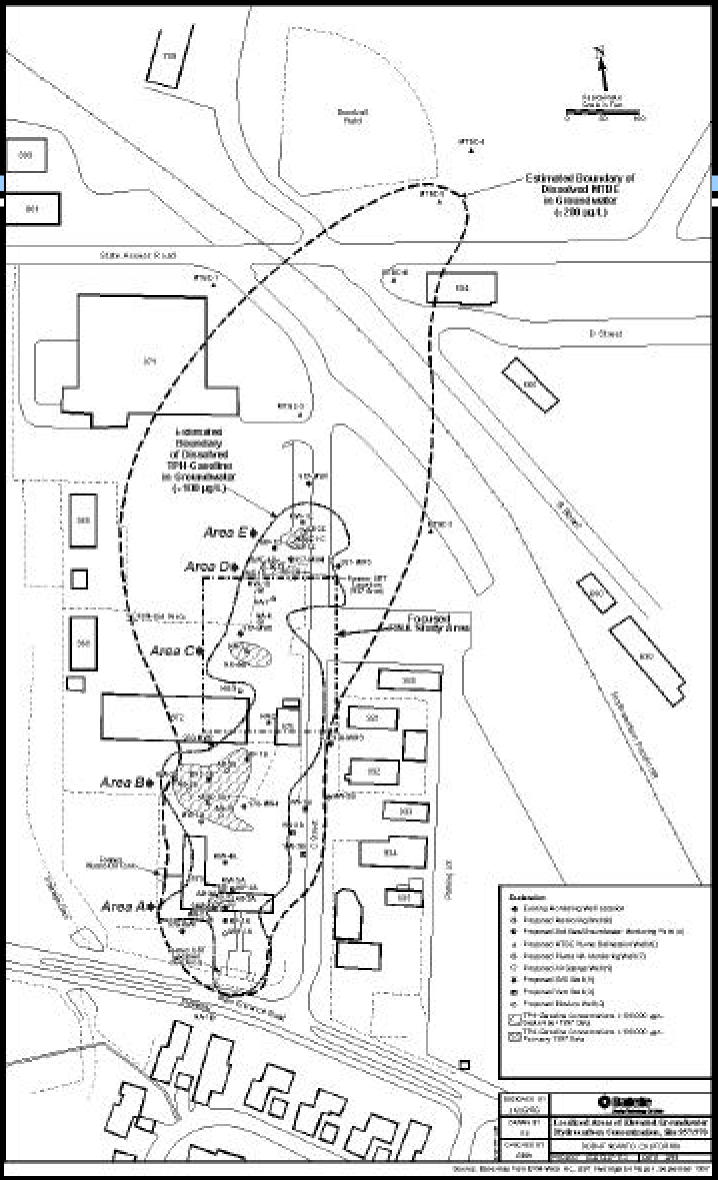
Site Map



Estimated Boundary of Dissolved MTBE in Groundwater
State Access Road
D Street
Estimated Boundary of Dissolved TPH-Gasoline in Groundwater
Area E
Area D
Area C
Area B
Area A
Proposed RNA Study Area

Objectives

- Evaluate site against RWQCB's low risk criteria (appropriate for intended future site use)
- If necessary, implement actions to meet low risk criteria

Low Risk Site Criteria

- Leak stopped/Free product removed
- Adequate site characterization
- Dissolved hydrocarbon plume is not migrating
- No receptors impacted (wells, surface water)
- No significant human health risk
- No significant ecological risk

DODHF Novato Design

- 10 sparge wells installed in 4 “hot spots”
  - Wells screen length 2 ft (13 to 15 ft bgs), approximately 5 ft below the water table
  - 10 cfm injected per sparge well
- SVE systems installed
  - Collect MTBE vapor until biodegradation can be demonstrated)
  - SVE designed to extract 2X the injection rate at each hot spot
- Two 25-hp oil-less compressors
- Possible system expansion after preliminary testing

Topics Covered

- What is air sparging?
- How does air sparging work?
- Implementing air sparging
  - Site characterization
  - Pilot studies
  - Field design
  - Process monitoring & site closure
- Cleanup times and costs
- Examples: Port Hueneme, CA and DODHF Novato, CA
- **Summary**

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Summary

- Used for treatment of contaminated groundwater - petroleum hydrocarbons & chlorinated solvents are good candidates
- If air reaches a location, treatment will occur, so air distribution is very important
- Air distribution is difficult to assess, so initial pilot tests are looking for reasons why air sparging cannot work

Summary (cont.)

- What to look for during pilot testing
  - Can you push air into the groundwater?
  - Is air distribution relatively homogenous?
  - Is the system safe?
- Two design approaches: standard and site-specific
- Use the standard design unless the site is very large or very deep

Summary (cont.)

- System is relatively easy to operate & maintain. Process monitoring involves primarily groundwater sampling (regulatory-driven) unless off-gas treatment is necessary
- In most cases, systems will operate for two years or less

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